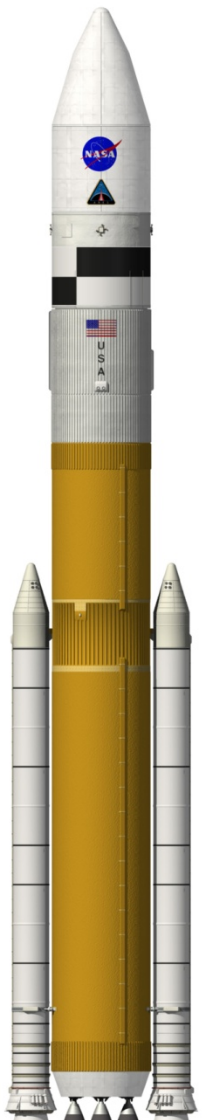


MSFC Advanced Concepts Office and the Iterative Launch Vehicle Concept Method

25 February 2011

Dennis Creech
Jacobs Engineering

Agenda

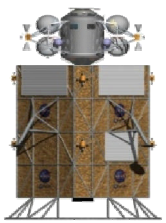
- Advanced Concepts Office (ACO) overview
- Earth-To-Orbit Team / Design Flow
- Modeling concepts in INTegrated ROcket Sizing (INTROS)
- Analyzing trajectory and performance
- Structural analysis
- Model wrap-up
- Typical sensitivities

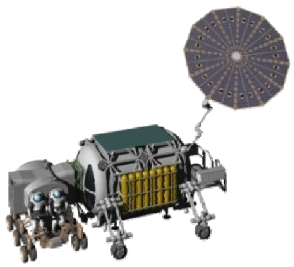
Advanced Concepts Office

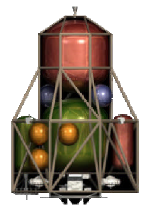
We Are An Office Specializing In Pre-Phase A & Phase A Concept Definition


RAVEN


Altair


LTAS

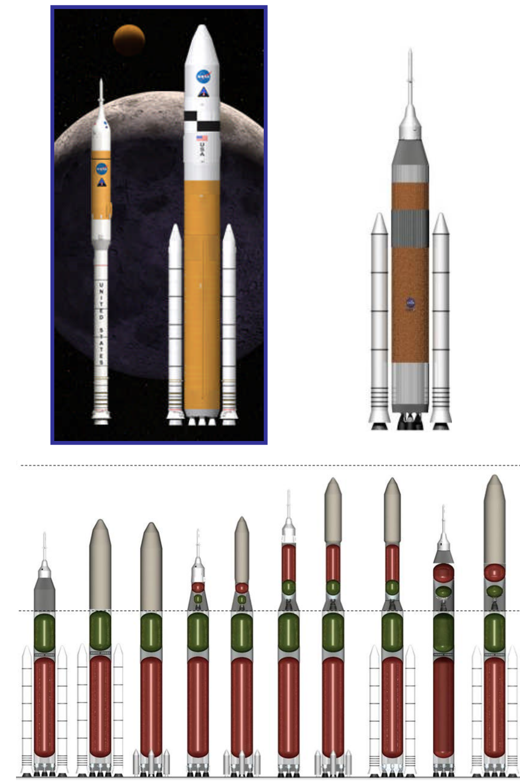

Habitat / Crew Systems


CRYOSTAT


CLARREO


AXTAR

In-Space

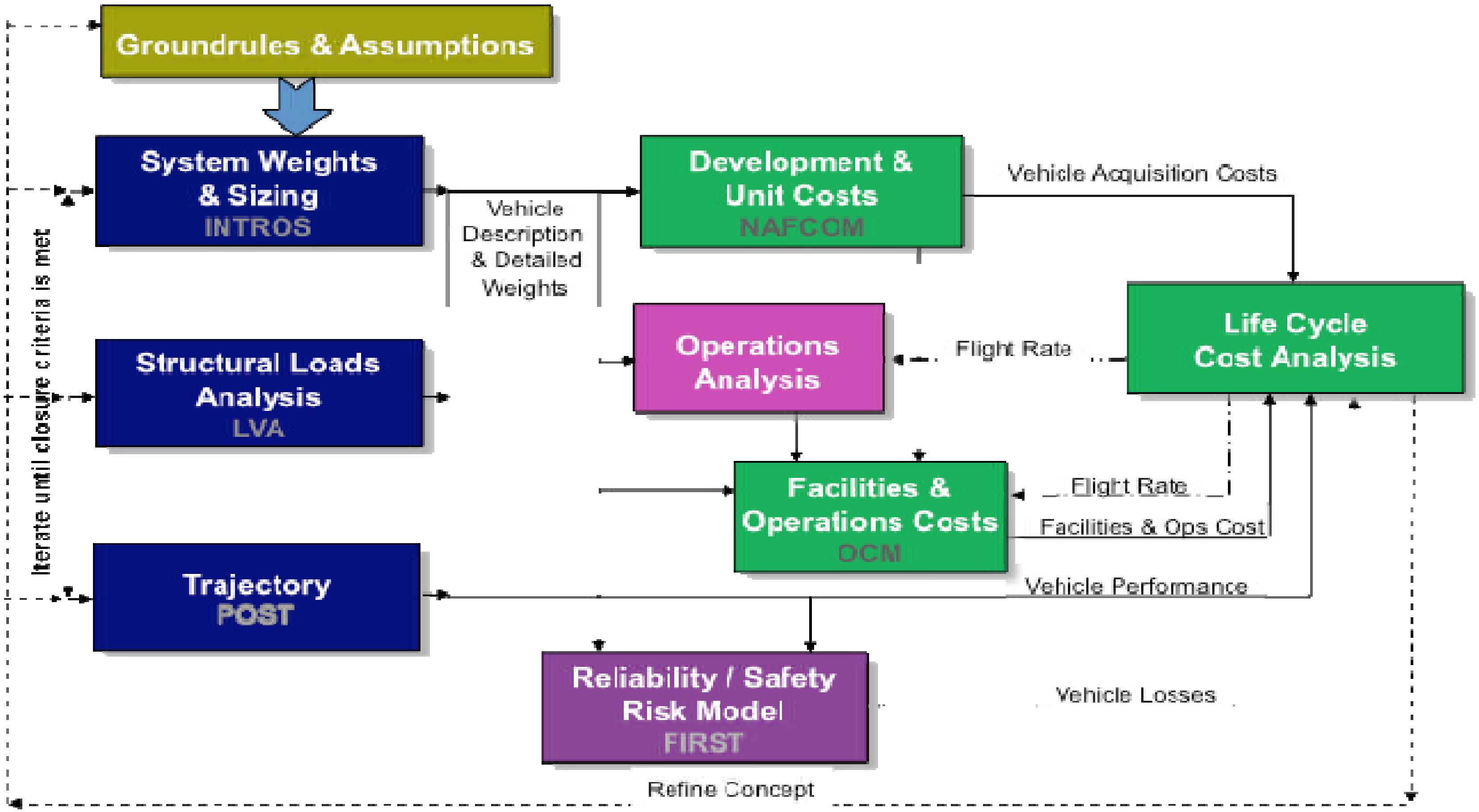


Earth-to-Orbit

ACO Earth-to-Orbit Team

- **High level concept performance**
- **Quick turnaround with high relative degree of accuracy**
- **Extremely useful for decision makers**
  - Identify potential
  - Eliminate poor performers
  - Data input to cost and risk evaluations
  - Sensitivities to mitigate poor concepts and enhance others
- **Recent activity**
  - Highly integrated in Agency/MSFC Heavy Lift Vehicle evaluations
    - Exploration Systems Architecture Study (ESAS)
    - Constellation
    - Review of U.S. Human Spaceflight Plans (Augustine Commission)
    - Heavy Lift Launch Vehicle Study (HLLV)
    - Heavy Lift Propulsion Technology (HLPT)
    - Human Exploration Framework Team (HEFT)
    - Space Launch System (SLS)

Earth To Orbit Design Flow



Processes can be adjusted if necessary

Integrated Rocket Sizing (INTROS)

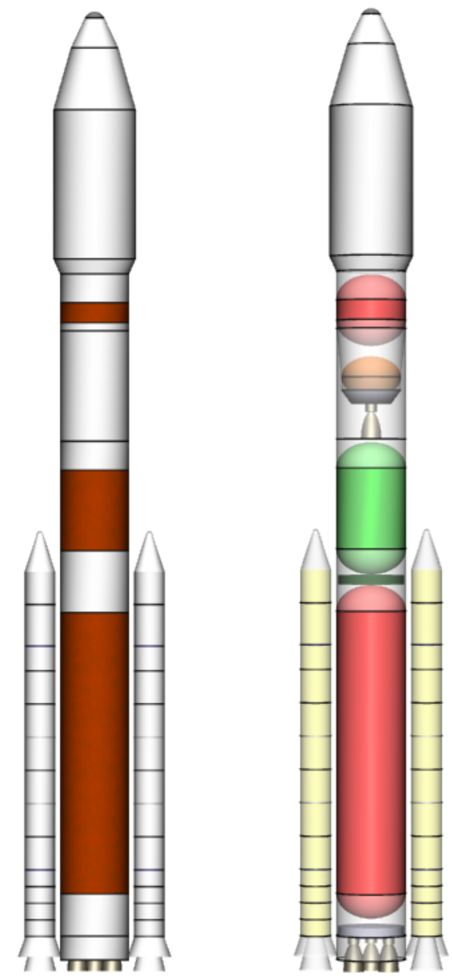
- **Developed at MSFC**
- **Written in Visual Basic for Applications**
- **Approx. 600 subroutines and user defined functions**
- **Robust Mass Estimating Relationship (MER) database**
- **Utilizes basic spreadsheet inputs**
- **Establishes**
  - Launch vehicle concept design
  - Stage sizing
- **Facilitates**
  - Integration of exterior analytical efforts
    - Structures, trajectories, element engineering
  - Vehicle architecture studies
  - Technology and system trades
  - Parameter sensitivities

Building INTROS Model

- **Typically begin with established vehicle file(s)**
- **Top-level vehicle layout**
  - Inline, number of stages, crew or cargo, boosters
- **Body Geometry**
  - Identify primary (load bearing) structures
  - Initially size propellant tanks
- **Propulsion System**
  - Engine type and arrangement
  - Define: mixture ratio, ullage, propellant properties
  - Evaluate fit and clearances
- **Equipment selections and routine**
  - Select items to be included in stage design
  - Routine is run that populates a mass accounting sheet

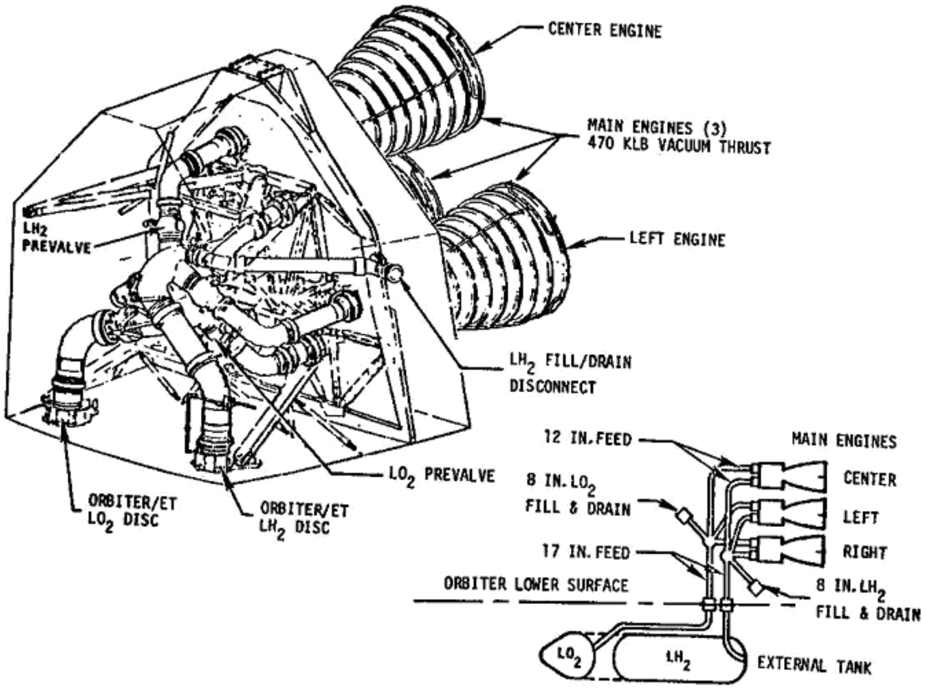
INTROS Mass Accounting

- **Primary Structures**
  - Interstage, intertank, skirts, tanks
  - Thrust/attach structure
- **Secondary Structures**
  - Closeout, fairings
  - Baffles (anti slosh/vortex)
  - Access tunnels
- **Separation Systems**
  - Stage-to-stage, fairing
- **Thermal Systems**
  - Closeout, thermal curtains, cork
  - Tank insulation
  - Equipment cooling



INTROS Mass Accounting

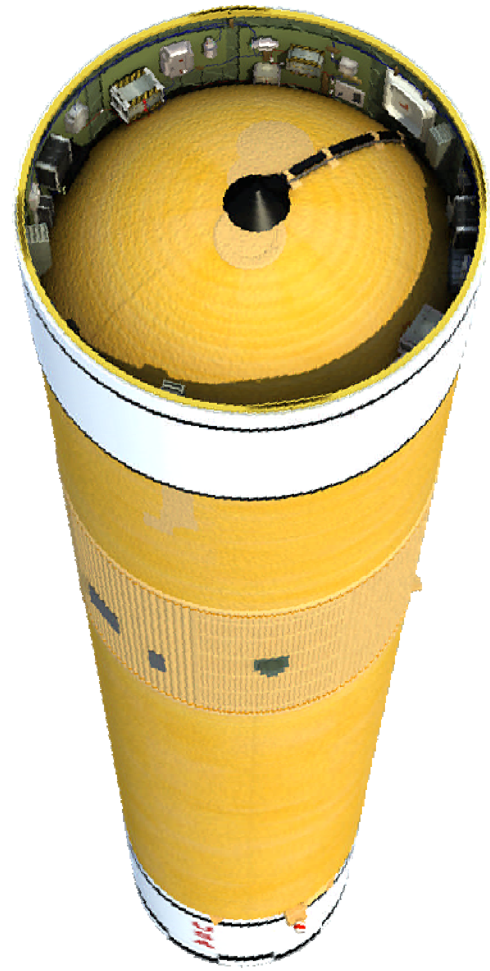
- **Main Propulsion System**
  - Engines
  - Engine installation
  - Feed Systems
  - Pressurization Systems
  - Pneumatic Systems
  - Thrust Vector Control
  - Upperstage Considerations
    - Repressurization
      - He bottles/lines
      - Restart equipment



Shuttle MPS

INTROS Mass Accounting

- **Power – Electrical**
  - Battery system
    - Cells
    - Conversion & distribution
    - Circuitry
- **Power – Hydraulic**
  - Hydraulic Auxiliary Power Units
  - Fuel storage & plumbing
  - Cooling system
- **Avionics**
  - Data mgmt/handling
  - Thrust Vector Control electronics
  - Instrumentation
  - Range safety
  - Guidance Navigation & Control



Mass Accounting Wrap-Ups

- **Stage Dry Mass with Growth**
- **Stage Burnout Mass**
  - Residuals
  - Reserves
  - In-flight losses
- **Stage GLOM**
  - Propellant
  - Purge helium
- **Vehicle GLOM**
  - Payload
  - Shroud
  - Provisions
  - Launch Abort System
  - Boosters

STAGE DRY MASS W/O GROWTH		
Dry mass growth allowance		
STAGE DRY MASS W/GROWTH (mdry)		
Residuals:		
Main propellant (liquid residual)		
Prop Tank Pressurization Gases:		
Liquid Oxygen tank		
Liquid Hydrogen tank		
Subsystems		
Reserves:		
Main propellant (FPR)		
Fuel bias		
APU reactants		
Inflight Fluid Losses:		
APU reactants		
STAGE BURNOUT MASS (mbo)		
Main Ascent Propellant:		
Liquid Oxygen		
Main Oxidizer Tank		
Oxidizer Feedlines		
Liquid Hydrogen		
Main Fuel Tank		
Fuel Feedlines		
Engine purge helium		
STAGE GROSS LIFTOFF MASS (mgross)		
Stage start propellant		
STAGE PRELAUNCH GROSS MASS (mplgross)		
Vehicle Stackup:		
Payload		
Payload shroud		
Payload provisions (external PL)		
Launch escape system (LES)		
Upper stage(s), gross		
Strap-on(s), gross liftoff		
Prelaunch gross		
Less strap-on start consumption		
Less stage start propellant		
VEHICLE GROSS LIFTOFF MASS (mgross_veh)		
Stage start propellant		
Strap-on start consumption		
VEHICLE PRELAUNCH GROSS MASS (mplgross_veh)		

POST ← **INTROS** → LVA

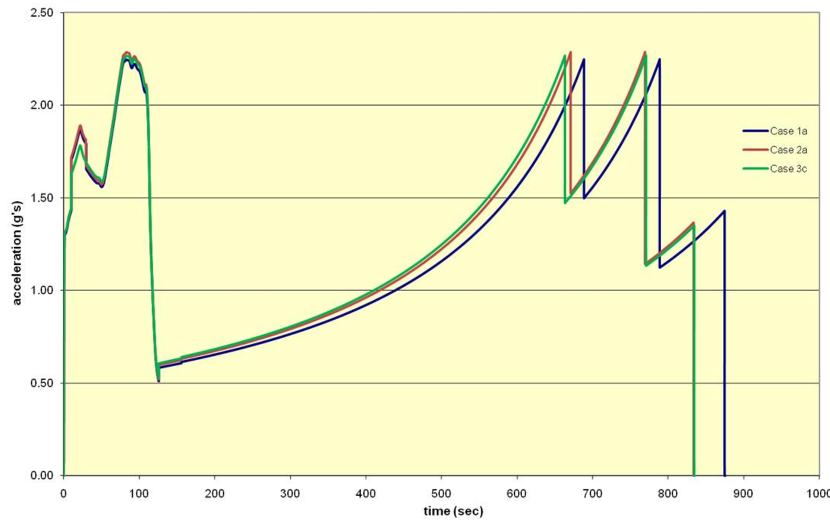
Transfer to Trajectory

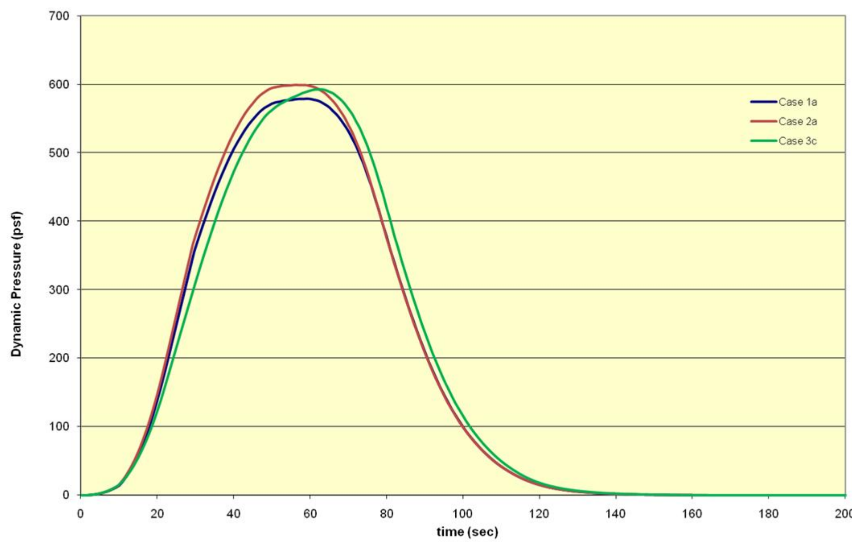
- **Program to Optimize Simulated Trajectories**
  - POST 3D
  - FORTRAN 77 based developed at Langley
  - Targets and optimizes point mass trajectories for powered/unpowered vehicle near arbitrary rotating, oblate planet
  - Offers discrete parameter optimization capability
- **POST inputs from INTROS**
  - Target payload
  - Gross Liftoff Mass/Stage dry masses
  - Propellant load
  - Reference areas
  - Booster data
  - Engine data
  - Shroud/LAS mass
  - Injected weight estimate
- **Additional inputs**
  - Initial position and orientation
  - Wind profile
  - Atmosphere model
  - Gravity model

Trajectory Analysis

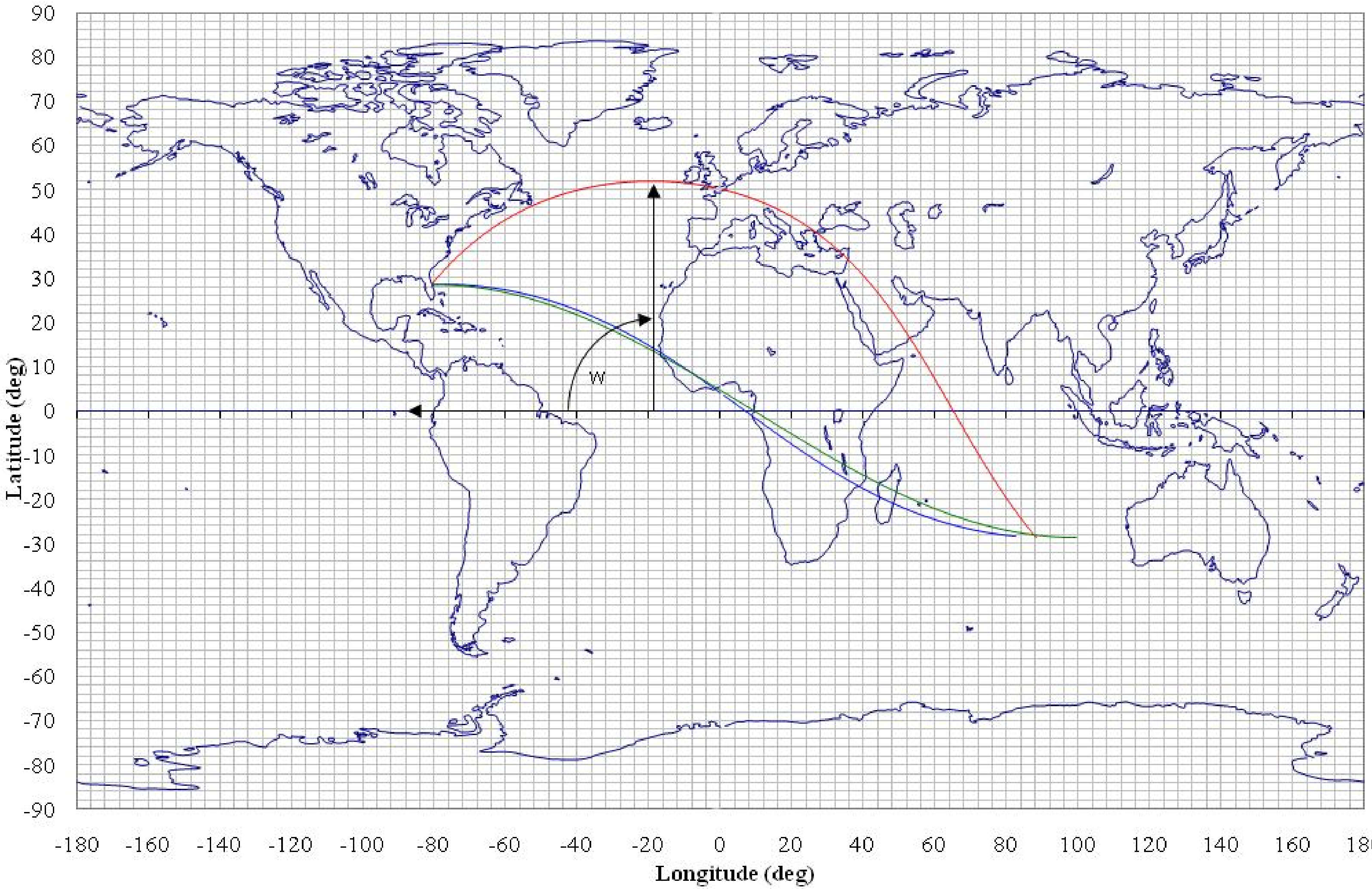
- **Constraints**
  - Determined by ground rules
  - Acceleration
  - Dynamic pressure
  - Final orbit
  - Free molecular heating rate: determines shroud drop

- **Outputs**
  - Optimized injected mass/payload
  - Flight profile to reach desired orbit
  - Vehicle orientation in orbit
  - Final state vector of vehicle





POST Output



POST ← INTROS → LVA

INTROS Model Revision

- **Data from performance run is fed into vehicle model**
  - Event timing with velocity
    - Booster burn/jettison
      - SRB overboard mass
    - Shroud jettison
    - Main Engine Cutoff and staging
    - Sub-orbital events
  - Injected mass
  - Total velocity change
- **Data used to resize stages**
  - Plus/minus propellant
  - Plus/minus payload
  - Propellant offload if stage fixed
- **Redundant calculations are performed**
  - Verifications
    - Engine power levels and throttle settings
    - Propellant flow rates and transient mass
    - Stage impulse
- **Eliminates a lot of common errors and adds scrutiny**

Transfer to Structural

- **Specific information is passed to the structural analyst**

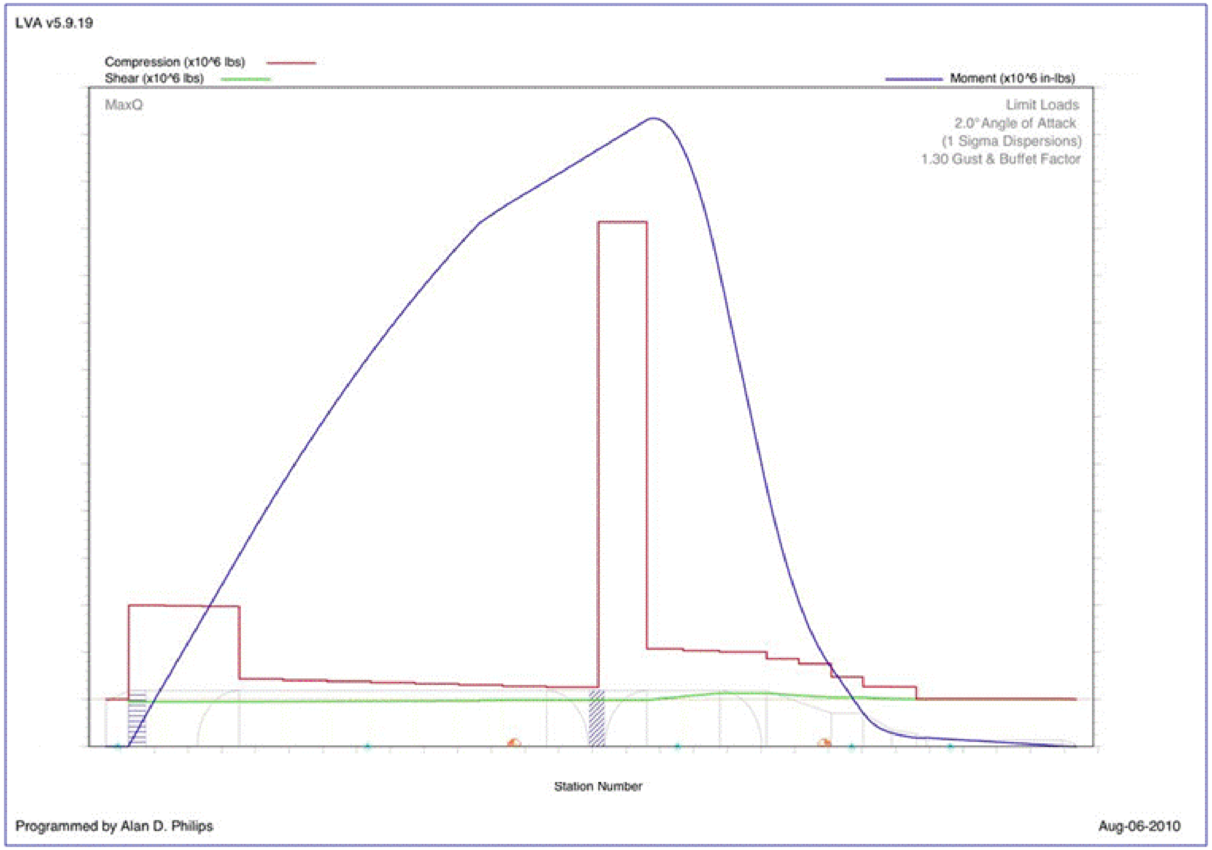
For LVA Program Input		VEHICLE:						STAGE:			
		lgth	dia1	dia2		vol	area			mass	unit mass
Description	shape	(in)	(in)	(in)	ecc	(ft^3)	(ft^2)	Mtl	Design	(lbm)	(lbm/x)
interstage cyl	cyl		331.00								
interstage	cone		331.00	331.00							
Forward skirt	cyl		331.00								
LOX forward dome	hobsprd		331.00		0.661						
LOX cylinder	cyl		331.00								
LOX aft dome	hobsprd		331.00		0.661						
Intertank	cyl		331.00								
LH2 forward dome	hobsprd		331.00		0.661						
LH2 cylinder	cyl		331.00								
LH2 aft dome	hobsprd		331.00		0.661						
Aft compartment	cyl		331.00								
Aft skirt	cone		264.80	331.00							
									Thrust Structure		
		Oxid	Fuel1			Max Q (lbf/ft^2)				Max G (g's)	
Total tank volume (ft^3)						Airfoil	Mass	Frnt area		Total vac thrust	
Tank propellant (lbm)						Group	(lbm)	(ft^2)		No of engines	
Prop density (lbm/ft^3)										Engine length	
Ullage pressure (psia)										Total engine mass	
Oxidizer description		Liquid Oxygen		liftoff T/W						Payload & prov mass	
Fuel1 description		Liquid Hydrogen		SRB sl						Stage gross L/O mass	
				Gross Liftoff						Stage burnout mass	
PBAN Trace				Total Booster Liftoff					Eng name		

Structural Analysis - LVA

- **Standalone application for quick turnaround launch vehicle structural design and analysis**
  - Provides itemized masses for primary structural elements
- **Written at MSFC in Visual Basic**
- **Uses time proven engineering analysis methods**
  - Material properties, load factors, aerodynamic loads, stress, elastic stability
  - Loads are run as single combined worst case
  - Also capable of analyzing event-specific loads
- **Program designed to operate with minimum input**
- **LVA and predecessors serving NASA for over 26 years**

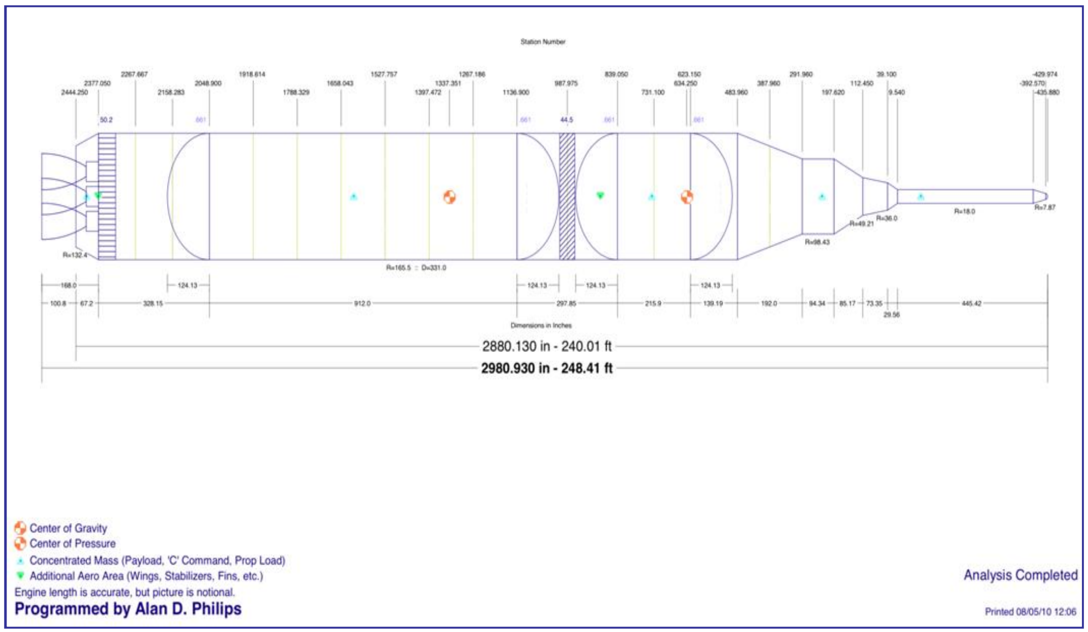
LVA Output

- **Itemized primary structure mass**
  - Tanks, skirts, shroud, intertank, interstage, thrust structure
- **Shear/bending moment/compression diagram**



LVA Output / INTROS Revision

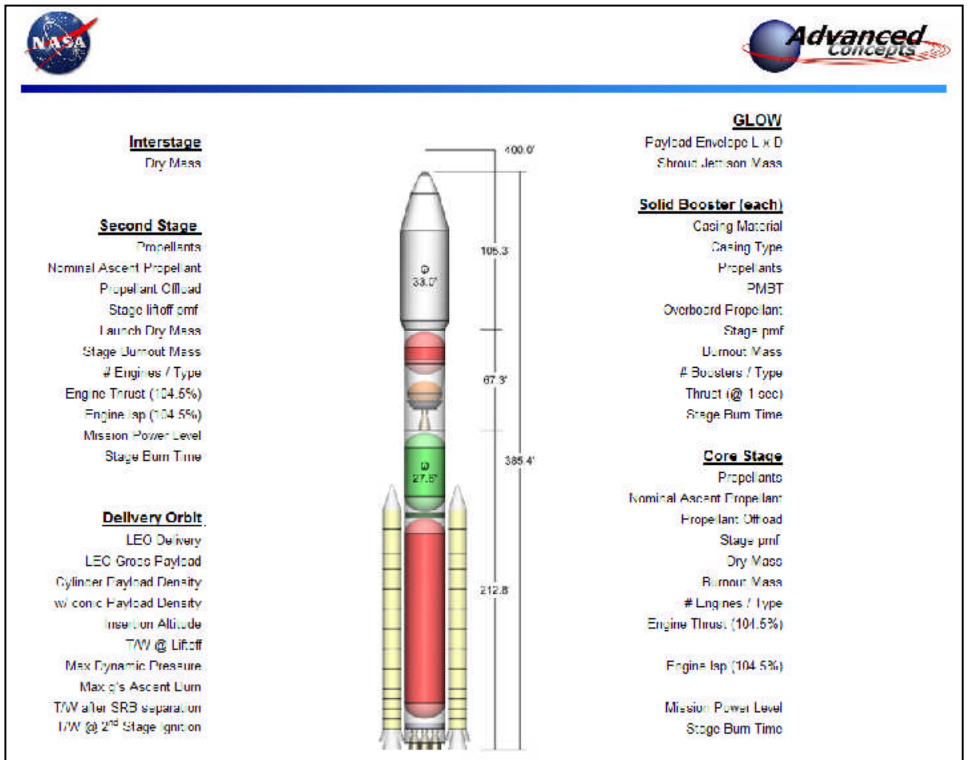
- **Scale depiction of concept**
  - Station numbering
  - CG, CP, and concentrated masses
  - Identifies interferences and illustrates margins



- **LVA-determined masses are incorporated in INTROS**
- **For resizing purposes, new unit mass ratios are integrated**

Closing the Loop

- **Iterative trajectory runs are made until injected mass predictions and actuals close within 300 lbm**
- **If loads break boundaries another LVA iteration is required**
- **Final report is generated (baseball card)**



Sensitivities Short List

- **Engine performance**
  - Power level, thrust, impulse, mass
- **Cargo or crew**
- **Shroud variables**
  - Geometry, material, jettison time, payload density
- **Boosters**
  - Propellant, trace, case material, size, thrust, attach point
- **Structural materials & design**
  - Composites integration, battleship construction, tank location, hammerhead
- **Mass Growth Allowance**
- **Ullage**
- **Flight Propellant Reserve**
- **Trajectory**
  - Insertions orbit/inclination
  - Aerodynamic load constraints
  - Throttle profiles/engine out

Conclusion

- **ACO ETO Team provides unique capability for NASA and MSFC**
- **Supported every agency / center level vehicle study from ESAS (2005) forward**
- **Jacobs ESTS employees are integral to this team**
- **The covered process is very streamlined & efficient**
- **Continued value through exterior input**

- **Thanks!**

- **Questions?**